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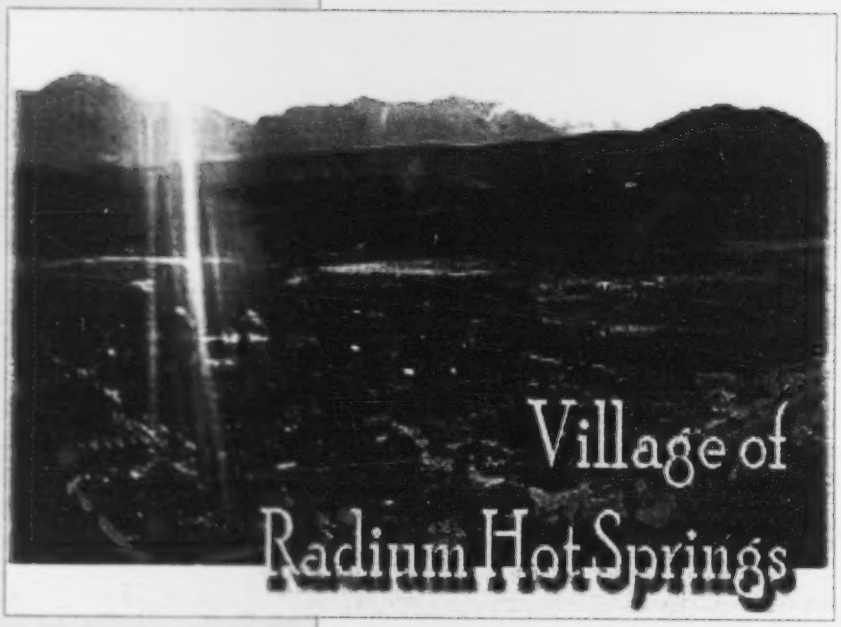
Ambient Air Quality Monitoring Report Radium, British Columbia

Particulate Matter - 1998 to 2007



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Preface

This report is one in a series of air quality reports issued by the Kootenay Regional Office for communities in the region where air quality is monitored. It is the intent of the Regional Office of the Ministry of Environment to publish air quality reports on our website (http://www.env.gov.bc.ca/epd/regions/kootenay/aq_reports/index.htm), to provide the information to industry and local government, other stakeholders and the public at large. By providing such information in a readily understood format, it is hoped that local air quality conditions can be better understood, and better decisions regarding air quality management can be made.

Acknowledgements

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Cover Photo:
Village Radium Hot Springs Chamber of Commerce

Ambient Air Quality Monitoring Report
Radium, British Columbia

Particulate Matter - 1998 to 2007

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Executive Summary

A vast amount of evidence exists to support the concern that airborne particulate matter, or PM, poses a significant health risk to humans. In response to this, the Ministry of Environment (MoE) has implemented air quality monitoring programs in various communities throughout British Columbia. The following report presents the results of the monitoring program established in the Village of Radium Hot Springs. The report was prepared by the MoE in an effort to inform the public, local government, and industry on the air quality conditions within the Radium airshed based on PM data collected during 1998 to 2007. The purpose of the report is to provide insight on how to effectively manage the local air quality conditions of Radium.

The Radium airshed specifically refers to a mass of air oriented along the Columbia River. The airshed extends north and south from the Radium town center approximately 40 km in each direction and extends westerly and easterly by approximately 10 km. The Purcell Mountain Range and the Rocky Mountain Trench land forms heavily influence the containment and/or dispersion of air pollutants with the airshed due to their proximity to Radium.

PM in Radium has been monitored by a device known as a "Partisol" manual sampler. The device was located on top of the Village of Radium office building and has been used for air quality monitoring purposes since 1998. The sampler was removed from this airshed in mid-year 2007 for deployment in another airshed of need. Between 1998 and 2007, air sampling was conducted for a 24 hour period on six-day cycle ensuring that data were generated for every day of the week (i.e., Wednesday, Tuesday, Monday etc.). Both monthly and yearly averages were then calculated using air quality data obtained from analysis of air filters (collected once every six days from the Partisol system).

The air quality monitoring program was implemented in Radium relatively recently (in 1998); therefore, developing long term air quality trends in Radium airshed is a more difficult task. For the most part, the data shows that Radium's PM levels, when compared with health impact indicators[1], are well below those of other communities within British Columbia. However, an increase in PM levels was observed between 2005 and 2006, bringing the concentrations closer to health impact indicators. For example, a health impact indicator typically used is the number of days per year that air particulate concentrations exceed 25 $\mu g/m^3$. The number of days local residents experienced elevated levels[2] of particulate matter in Radium during 2005 and 2006 was almost double of that in 2004, but still very low relative to other interior communities. Such an increase could indicate that Radium may be on the cusp of an upward trend in ambient levels of particulate matter. However, the limited data collection done in 2007 suggests otherwise, since the PM levels decreased during this monitoring period. The ministry hopes to collect more air quality data in future to re-evaluate whether PM levels are increasing or decreasing in Radium airshed.

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[1] For the purposes of the report, "health impact indicators" refer to the various thresholds used for national or provincial air quality standards or objectives. Such thresholds are established to indicate adverse effects to human health as reported by health professionals. See Section 2.0.

[2] "Elevated levels" of particulate matter refers to airborne particulate matter concentrations that exceed 25 $\mu g/m^3$.

Particulate matter in Radium originates from multiple sources including fugitive dust from traffic, woodstove smoke, industrial emissions, slash burning activities, and forest fires. The extent of impact that a source of particulate matter has on the Radium airshed may depend on the time of the year. For example, particulate matter generated from vehicular traffic could increase during months of high tourism.

The MoE has compared data collected from the Radium airshed monitoring program (from 1998 to 2007) with air quality objectives used in British Columbia and does not consider the air quality in the Radium airshed to be a major concern. However, both the Village of Radium and the MoE are interested in planning a short-term surveillance sampling campaign within three to five years to confirm that the health indicators remain positive for this community's air (see above). Human physiological responses to airborne particulate matter can occur at any level. So although particulate matter levels in Radium comply with provincial air objectives, the public, government and industry should be continuing their efforts to improve air quality within the Radium airshed.

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1.0 Introduction

There is mounting evidence that airborne **particulate matter,** or PM, poses a significant health concern and thus the Ministry of Environment (MoE) has instituted a network of monitoring for PM. The data resulting from the monitoring has been compiled and analysed by the MoE for this report to inform the public, local government, and industry about particulate matter levels in the Radium **airshed**[3]. This document will also discuss trends in air quality data and factors that have possibly influenced the levels of PM measured in the community. By providing this information it is hoped that local air quality conditions can be better understood and decisions regarding air quality management will be well informed.

Many pollutants are known to have detrimental effects on human and environmental health. The common ones monitored in BC are: nitrogen dioxide, sulphur dioxide, total reduced sulphur, carbon monoxide, ozone, formaldehyde, and particulate matter. However, in most Kootenay Region communities, including Radium, particulate matter is the most serious health concern. As such, this was our primary monitoring focus and this report will deal only with the assessment of particulate matter.

"Particulate matter" may sound like a scientific expression, but it breaks down into simple concepts. Particulates are tiny solid or liquid particles that come in many shapes and sizes, and are from many different sources.

The majority of particulates that have a negative effect on human health are 10 micrometres or less in diameter (PM_{10}). A micrometre (µm) is a millionth of a metre, so PM_{10} is roughly the same size as bacteria. Like bacteria, PM_{10} is invisible to the naked eye and small enough to be inhaled into our lungs.

Fine particulate matter is small enough to enter our airways and lungs as we breathe.

Figure 1 demonstrates that particulate matter comes in a wide range of sizes and differs in chemical composition and source. Collectively, PM_{10} includes the **coarse fraction** ($PM_{10\text{-}2.5}$), the **fine fraction** ($PM_{2.5\text{-}0.1}$), and the **ultra-fine fraction** ($PM_{<0.1}$).

The fine fraction ($PM_{2.5}$) is comprised of particles smaller than 2.5 µm that generally are formed by chemical reactions. $PM_{2.5}$ often is generated directly through combustion or burning; however, $PM_{2.5}$ also may be created indirectly from reactions in the atmosphere (secondary PM). Common sources of $PM_{2.5}$ include smoke from burning of yard waste, slash burning, residential woodstoves, exhaust from automobiles, and industrial smoke stacks. In addition to sources associated with human activities, $PM_{2.5}$ also is generated through natural processes such as forest fires.

[3] A geographic area that, because of topography, meteorology, and/or climate, is frequently affected by the same air mass.

Secondary PM is formed through atmospheric reactions involving oxides of nitrogen, sulphur dioxide, volatile organic compounds, and/or ammonia from natural (*e.g.*, tree metabolism, wildfires) or human-caused emissions (*e.g.*, industrial processes, vehicles). High concentrations of secondary PM can produce an effect known as blue **haze**. Blue hazes impair visibility of scenic landscape and thus can be economically detrimental to communities with high tourism such as Radium. Secondary PM of the fine fraction may remain suspended in the atmosphere for extended periods of time (depending on meteorological conditions) resulting in prolonged periods of poor air quality.

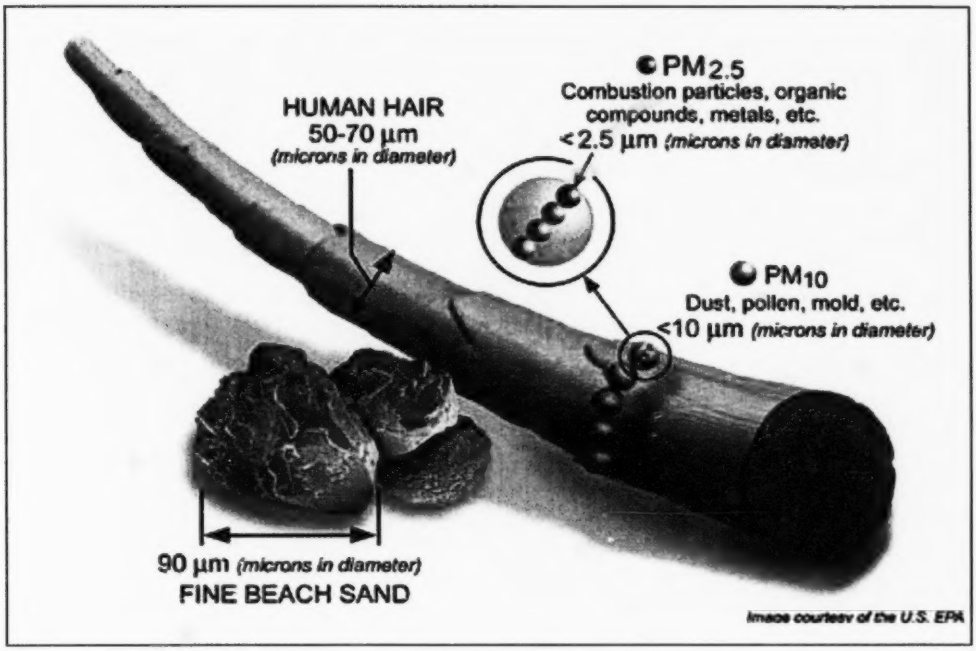

Figure 1: Relative sizes of particulate matter

The coarse fraction consists of particles between 2.5 µm and 10 µm in diameter. Particles of this size often assume the form of **fugitive dust**, which consists of finely ground rock and clay, and come from both human and natural sources. The most common source of fugitive dust caused by human activity is unpaved roads, or paved roads that have had sand and salt applied for winter travelling. In spring, when the roads are no longer frozen or wet, traffic grinds up the gravel into finer and finer particles. These are then either thrown into the air by passing traffic, or picked up by strong winds. Other sources of coarse fraction particulate matter include industrial emissions (e.g., fly-ash) and sea salt. Depending on meteorological conditions, it is possible for the particles to stay suspended for hours or days, resulting in poor air quality. Natural sources of fugitive dust are river, lake, and reservoir banks and dust storms, problems that affect communities like Revelstoke when water levels are low.

1.1 Particulate Matter and Health Effects

PM is the air pollutant of greatest concern in the Radium airshed and throughout the Kootenay Region. There are two main reasons for the concern over this pollutant: 1) these particles are small enough to enter our airways and lungs as we breathe, and 2) the emission sources typically found in interior BC tend to produce significant amounts of PM.

Two types of PM exist that produce adverse health effects in people: inhalable particulate matter and respirable particulate matter. **Inhalable particulate matter**, also known as PM_{10}, is composed of particles small enough to be carried into our airways. However, some of these particles are large enough to get trapped in the larger airways and do not reach the smallest cavities within our lungs. **Respirable particulate matter** consists of the fine and ultra-fine fractions of PM (also termed as $PM_{2.5}$) and is composed of particles small enough to travel into the deepest parts of our lungs.

Particulate matter can cause a range of health effects in people, from annoying symptoms such as a runny nose to increased premature mortality in extreme cases. Recent studies have associated particulate matter with longer-term health effects such as lung cancer.

Based on evidence from epidemiological studies, the effects of exposure to PM_{10} and $PM_{2.5}$ concentrations are reflected in:

- Increases in mortality due to cardiorespiratory diseases.
- Increases in hospitalization due to cardiorespiratory diseases.
- Decreases in lung function in children and asthmatic adults.
- Increases in respiratory stresses that can lead to absenteeism from work or school and a restriction in activities.
- Chronic effects including increased development of chronic bronchitis and asthma in some adults, and reduced survival.

Particulate matter can cause a range of effects ... from annoying symptoms to premature mortality.

Those most susceptible to PM-related health impacts are children, the elderly, asthmatics, and people with pre-existing cardiorespiratory diseases.

Previous medical studies have determined that no apparent safe lower threshold for adverse health effects exists for particulate matter[4]. Such a finding has prompted

[4]http://www.hls.gov.bc.ca/pho/pdf/phoannual2003.pdf

governments to review and strengthen air quality criteria for PM in order to reduce the risks to Canadians[5].

2.0 Air Quality Objectives/Standards

To evaluate air quality, objectives and standards have been introduced that provide what are considered to be acceptable levels of PM_{10} and $PM_{2.5}$ in British Columbia.

2.1 Provincial Objectives

Recognizing the threat that PM_{10} poses to human health, the MoE established an air quality objective for PM_{10} of 50 $\mu g/m^3$ (24-hour average) in 1995. This level is comparable to the maximum acceptable level in the **National Ambient Air Quality Objective** (NAAQOs) system[6] or a provincial Level B objective.

More recent health evidence suggests that $PM_{2.5}$ poses a greater health risk than do the coarser fractions. In response to this concern, the MoE has established (in the spring of 2008) an air quality objective for $PM_{2.5}$ of 25 $\mu g/m^3$ (24-hour average)[7].

2.1.1 Air Quality Index

The **air quality index** (AQI[8]) is the most familiar indicator of air quality to British Columbians, providing the public with a meaningful measure of outdoor air quality via daily reports available on the Internet. It is determined by comparing air quality measures for contaminants such as ozone, carbon monoxide, and PM to levels established by the federal or provincial governments. In provincial AQI calculations, PM_{10} levels are compared to reference levels of 25, 50, and 100 $\mu g/m^3$ (comparable to provincial reference Levels A, B and C, respectively).

The data analysis of this report uses the reference levels of the AQI system to count the number of days in a year that each level is exceeded and reports the percentage of days that each level is exceeded. Along with these guidelines, British Columbia also references other national standards described below.

[5] WGAQOG (1999) *National Ambient Air Quality Objectives for Particulate Matter. Part 1: Science Assessment Document.* A report by the CEPA/FPAC Working Group on Air Quality Objectives and Guidelines. Minister, Public Works and Government Services.

[6] For more information about NAAQO, see: http://www.hc-sc.gc.ca/ewh-semt/alt_formats/hecs-sesc/pdf/pubs/air/naaqo-onqaa/particulate_matter_matieres_particulaires/summary-sommaire/98ehd220.pdf

[7] Air quality objectives established by MoE in the spring of 2008 are currently in the review phase among provincial stakeholders and are subject to change.

[8] A numerical index of particulate matter, ozone and other common air pollutants. From the AQI, we can effectively rate air quality as "Good", "Fair", "Poor", or "Very Poor". For guidance on how to calculate the AQI, see http://a100.gov.bc.ca/pub/aqiis/air.info.

2.2 National Ambient Air Quality Objectives (NAAQOs)[9]

The NAAQOs identify benchmark levels of protection for people and the environment. NAAQOs guide federal, provincial, territorial and regional governments in making risk-management decisions, playing an important role in air quality management. Local source permitting, air quality index calculations, and the development of provincial objectives and standards all make use of the NAAQOs.

The NAAQO system defines three objectives: a maximum desirable level, a maximum acceptable level, and a maximum tolerable level. With the exception of the maximum tolerable objective, the NAAQOs are viewed as effects-based long-term air quality goals (i.e., goals determined by the epidemiological effects established by statistical analysis).

2.2.1 Reference Levels

Although negative health effects can occur at any level of particulate matter, the **CEPA/FPAC**[10] Working Group on Air Quality Objectives and Guidelines recommended reference levels of 25 $\mu g/m^3$ (24 hour average) for PM_{10} and 15 $\mu g/m^3$ (24 hour average) for $PM_{2.5}$. These levels were intended to represent estimates above which there are demonstrated (i.e., statistically significant) effects on human health and the environment. They were not intended to be used as enforceable air quality objectives, but as the basis for establishing goals for long-term air quality management.[11]

2.2.2 Exposure Estimates

Risk to human health is believed to increase linearly with PM concentrations. Hence, a simple estimate of exposure, and therefore risk, can be estimated by summing the concentration above a threshold or reference level over a specific period of time. The method used in this report to calculate exposure is explained in Appendix B.

2.3 Canada-wide Standards (CWS) Agreement

Under the Canada-wide Accord on Environmental Harmonization, the Canadian Environment Ministers (with the exception of Quebec) ratified the Canada-wide Standards (CWS) for PM and ozone in July 2000[12]. The CWS process is expected to provide new tools for the management of environmental issues of national interest.

The standards for particulates are based on daily average $PM_{2.5}$ measurements over three consecutive calendar years. The **98th percentile** is often used in analyses and

[9] National Ambient Air Quality Objectives: http://www.hc-sc.gc.ca/ewh-semt/pubs/air/naaqo-onqaa/index-eng.php

[10] Canadian Environmental Protection Act Federal-Provincial Advisory Committee

[11] CEPA/FPAC Working Group on Air Quality Objectives and Guidelines (1999) *National Ambient Air Quality Objectives for Particulate Matter. Part 1: Science Assessment Document.* Minister, Public Works and Government Services.

[12] Canada-wide Standards Agreement: http://www.ccme.ca/ourwork/air.html?category_id=99

comparisons because it reduces the bias caused by a single extremely high reading. For each year, the 98th percentile of the daily averages is determined and then averaged for the last three calendar years. This value, referred to in this report as the **CWS Indicator**, can then be compared to the standard and to other communities.

The adopted standard for $PM_{2.5}$ is 30 $\mu g/m^3$. Although there was no standard or objective set by the CWS for PM_{10}, the previously described "CWS Indicator" is used to analyze historical trends in ambient air quality in this report.[13]

2.4 Comparison of Federal and Provincial Air Quality Criteria

Three reference levels (A, B, and C) have been defined in BC for PM_{10} based on the NAAQO system of the federal government (see Table 1). Achieving Level A concentrations (less than 25 $\mu g/m^3$) creates an atmosphere of good air quality where humans and environment can flourish. Subscribing to Level B concentrations (25 to 50 $\mu g/m^3$) will provide sufficient protection for the health of the majority of individuals but may allow discomfort to occur in sensitive individuals. At Level C concentrations (50 to 100 $\mu g/m^3$), risks to human health become more severe, and concentrations of particulate matter must be reduced to adequately protect human health.

Table 1: Comparison of provincial and federal air quality criteria.

Level	Description	AQI Rating (PM_{10} concentration in µg/m3)	Equivalent federal objective
A	Provide long term protection	Good - up to 25	Maximum desirable
B	Provide adequate protection, but may affect personal comfort.	Fair – 25 to 50	Maximum acceptable
C	Appropriate action required to protect human health	Poor – 50 to 100	Maximum tolerable

The AQI rating (in the above table), converts the concentrations of PM_{10} pollutants to a common-language, unit-less scale to indicate health implications. To clarify, threshold levels of PM_{10} are identified by describing what the quality of ambient air in a day would be if said threshold is surpassed. For example, if the average PM_{10} concentration throughout a day is below 25 $\mu g/m^3$, the day is described to have "good" air quality (in terms of PM_{10}). However, if the day experienced a higher average PM_{10} above 50 $\mu g/m^3$, PM_{10} would have exceeded both the "good" and "fair" thresholds, and the day is considered to be of "poor" air quality.

[13] The B.C provincial government has an objective for PM_{10}, and the federal government has a standard for $PM_{2.5}$, but there is no common objective or standard for both pollutants.

3.0 Air Quality Monitoring in Radium

Particulate matter levels are measured to determine the exposure concentrations of people in BC communities. Monitoring enables regulators and policymakers to identify the air quality impacts of current sources and determine the impacts of new sources or emission control measures. Monitoring over long periods of time allow communities to assess trends that will show if air quality is getting better or worse. In addition, long-term monitoring allows comparison with standards and objectives to assess how Radium's air quality is doing in relation to health standards. Comparisons can also be done between the air quality in Radium and in other BC communities for which air quality is monitored.

To characterize particulate matter levels in BC, MoE has been monitoring particulate matter levels throughout the province for a number of years. Figure 2 displays the locations where air quality monitoring is done in the Kootenays, and the types of pollutants sampled. While the earliest monitoring dates back to the early 1970's, the large-scale monitoring effort began in 1989.

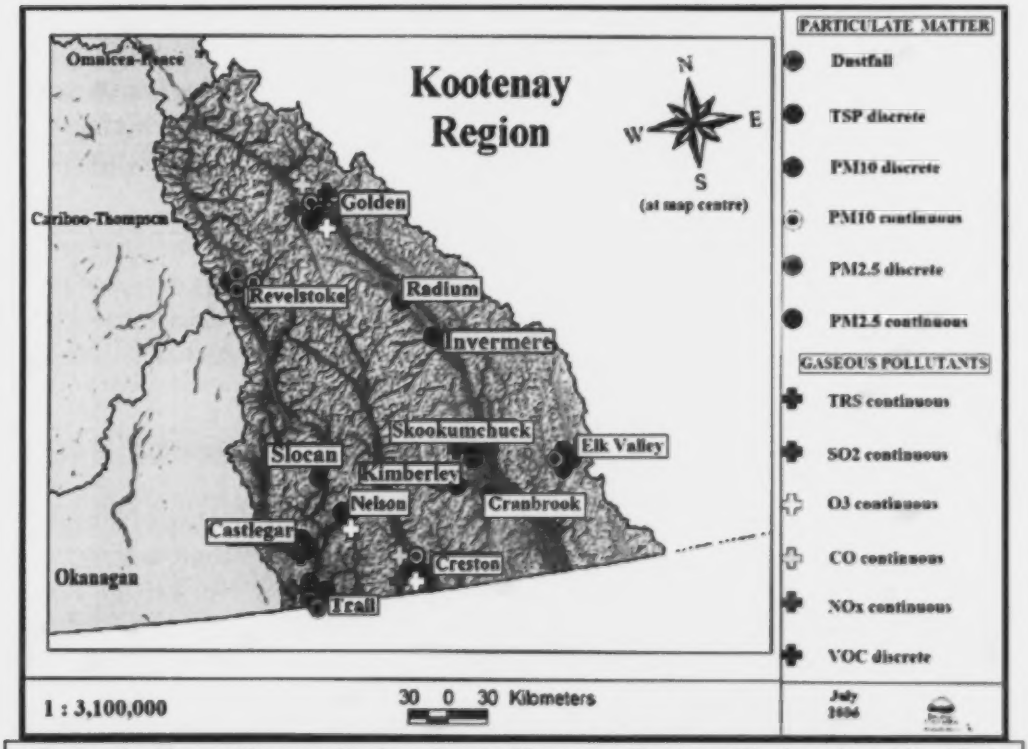

Figure 2: Air quality monitoring sites in Kootenay Region. The locations identified depict all operating air quality in the Kootenay Region stations on January 1, 2006.

Air quality in Radium has been monitored by a "Partisol" manual sampler located at the service garage in the Village of Radium office building (Figure 2). Manual samplers draw air through a pre-weighed filter for a specified period (usually 24 hours) at a known

flow rate. The filter is then removed and sent to a laboratory to determine the gain in filter mass due to particle collection. Ambient PM concentration is calculated on the basis of the gain in filter mass, divided by the product of the sampling period and sampling flow rate. Differently sized sampling head inlets allow for the measurement of coarser PM, PM_{10}, or $PM_{2.5}$. Additional analysis can also be performed on the filter to determine the chemical composition of the sample, but this is not done routinely.

Prior to 2002, samples were taken to correspond to the operational periods of a wood waste incinerator at the Slocan Forest Products saw mill. After 2002, the Partisol sampler was set to collect one sample of PM_{10} once every six days and no longer conformed to the operational schedule of surrounding industry.

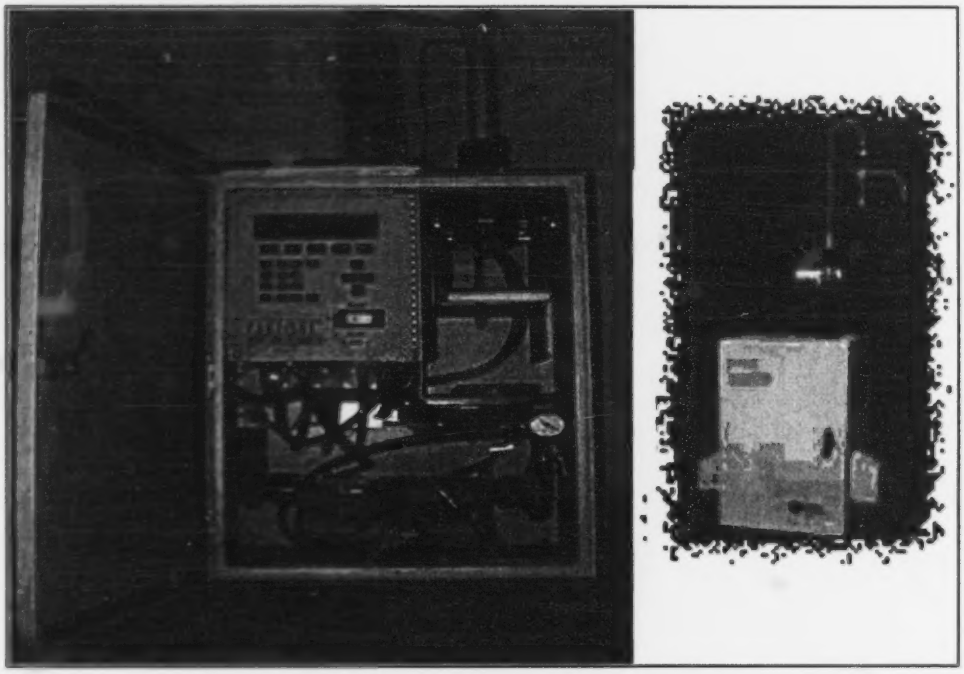

Figure 3: Partisol sampler in Radium

4.0 Airshed Description

In general, an 'airshed' is a body of air in which management strategies of any individual emission source can have an effect. For example, a backyard burning bylaw in Radium could likely positively influence the air throughout the Village of Radium and the surrounding areas but would probably not affect air quality in Golden or Cranbrook. However, this definition is complicated by that fact that fine PM can travel thousands of kilometres.

For airshed management purposes, the Radium airshed roughly refers to the elongated mass of air along the Columbia River, 40 kilometres to the north and to the south, and 10 kilometres either side of the town centre, to the west and to the east (Figure 4). These boundaries are somewhat topographic, with the mountain ranges holding the air mass in the valley.

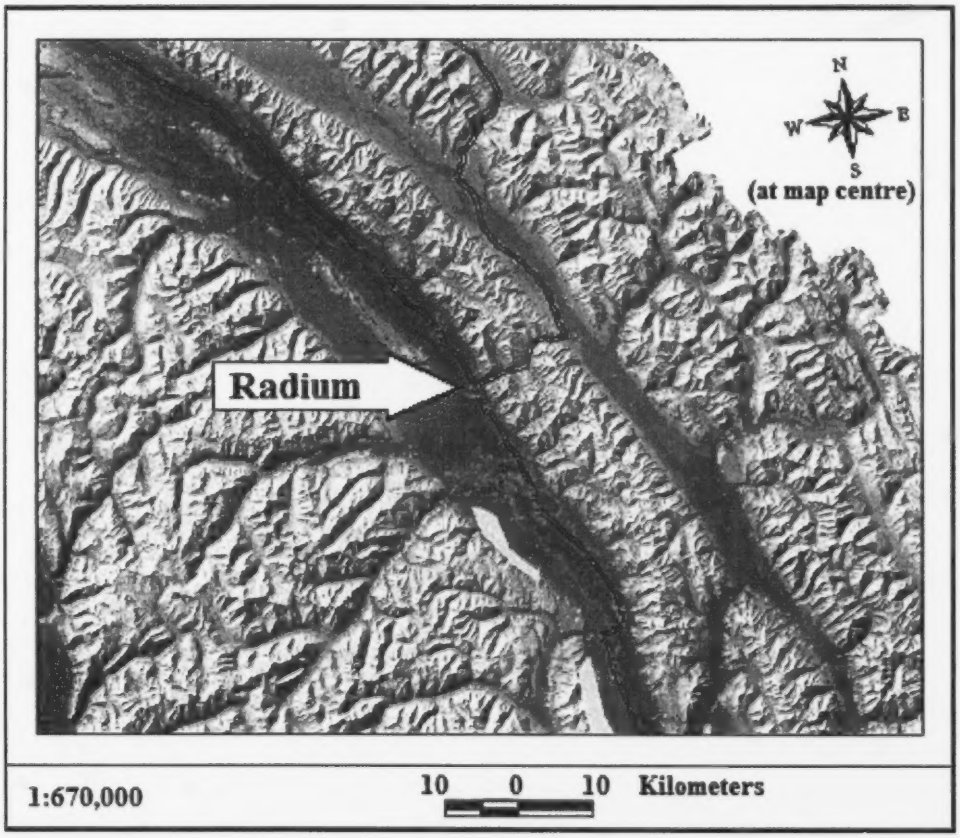

Figure 4: Village of Radium Hot Springs airshed. Approximately 40 km along the valley in either direction, and with a width from ridgeline to ridgeline

4.1 Influences on Air Quality: Emissions

Provincial Overview

The sources of particulate matter vary from community-to-community and from season-to-season. Based on the year 2000 provincial **emissions inventory**[14], an estimated 850 thousand tonnes of particulate matter were released into the atmosphere as **primary pollutants**[15]. Note that this estimate is only for emissions that result from human activities (i.e., **anthropogenic** emissions).

Though provincial summaries may not reflect relative source contributions in individual communities such as Radium, they are useful as benchmarks for comparison.
For both PM_{10} and $PM_{2.5}$, the contributions from **area sources**[16] (e.g., fireplaces, wood stoves and backyard burning), **mobile sources** (e.g., diesel trucks), and road dust are important to local air quality. Area sources are numerous and/or widespread and are located in close proximity to where we live. **Point sources**[17] of PM in the region include industrial operations, such as wood and pulp mills.

As summarized in Figures 5 and 6, these are the key points from the 2000 Emissions Inventory with regard to particulate matter in the BC Interior:

PM_{10}

- Point sources contribute 45% of PM_{10} emissions, with 23% coming from the wood industry and 11% coming from the pulp and paper industry.
- Area sources are collectively responsible for 46% of PM_{10} emissions; 25% are from prescribed burning, 11% are from agricultural practices and 9% are from residential fuel wood combustion.

$PM_{2.5}$

- Area sources account for almost half (49%) of $PM_{2.5}$ emissions, with significant contributions from prescribed burning (33%) and residential fuel wood combustion (13%).
- Point sources contribute 40% of $PM_{2.5}$ emissions, with 20% from the wood industry and 12% the from the pulp and paper industry.

[14] MWLAP (2004) *2000 Emissions Inventory Analysis Report*. Note that the estimates contained in this report include neither natural sources such as wildfires and biogenic emissions, nor fugitive road dust.
[15] Primary pollutants are the chemicals that are emitted directly into the atmosphere. Secondary pollutants are the result of primary pollutants reacting chemically or physically to form different compounds.
[16] An emission source of pollutants that covers a large, and sometimes poorly defined, area.
[17] An emission source of pollutants that remains in a small identifiable area.

Secondary particles[18] were not considered in the emissions inventory estimates, although studies limited to the Lower Fraser Valley indicate that they may comprise up to 50% of the fine particulate matter collected during the summer. Sulphur dioxide (SO_2), nitrogen oxides (NOx), various hydrocarbons, and ammonia (NH_3) are important gases involved in the formation of secondary particles[19,20]. Major sources of SO_2 include the cement, pulp and paper, and petroleum industries, as well as motor vehicles[21]. Approximately 75% of NOx emissions in the Lower Mainland are from motor vehicles and marine vessels. Motor vehicles, solvent usage and vegetation[22] contribute to over 70% of hydrocarbon emissions. Agricultural use of fertilizers is the dominant source of NH_3.

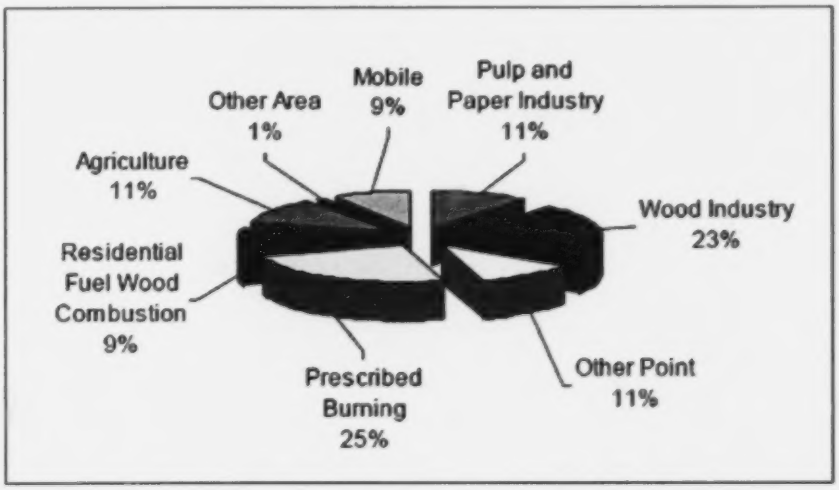

Figure 5: Human-caused sources of inhalable particulate matter (PM_{10})
The figure displays information for areas outside the Lower Mainland, and exclude natural sources, such as wildfires or **biogenic** emissions, and fugitive road dust.

Source: 2000 Emissions Inventory Analysis Report, MWLAP. 2004.

[18] Particles that are not directly emitted into the atmosphere, but are produced by chemical and physical processes. See Appendix A: Secondary Pollutant.
[19] Lowenthal D.H., D. Wittorff, and A.W. Gertler (1994) *CMB Source Apportionment During REVEAL - Final Report*. Air Resources Branch, British Columbia Ministry of Environment, Lands and Parks.
[20] Pryor S.C. and D. Steyn (1994) *Visibility and ambient aerosols in south-western British Columbia during REVEAL*. British Columbia Ministry of Environment, Lands and Parks.
[21] ARB (1994) *1990 British Columbia Emissions Inventory of Common Air Contaminants*, Air Resources Branch, British Columbia Ministry of Environment, Lands and Parks, Victoria, B.C., December.
[22] "Biogenic" sources are a subset of natural sources and include only those sources that result from biological activity. Biogenic emissions represent a significant portion of the natural source emissions. VOC, NOx, and the greenhouse gases can all be emitted from biogenic sources.

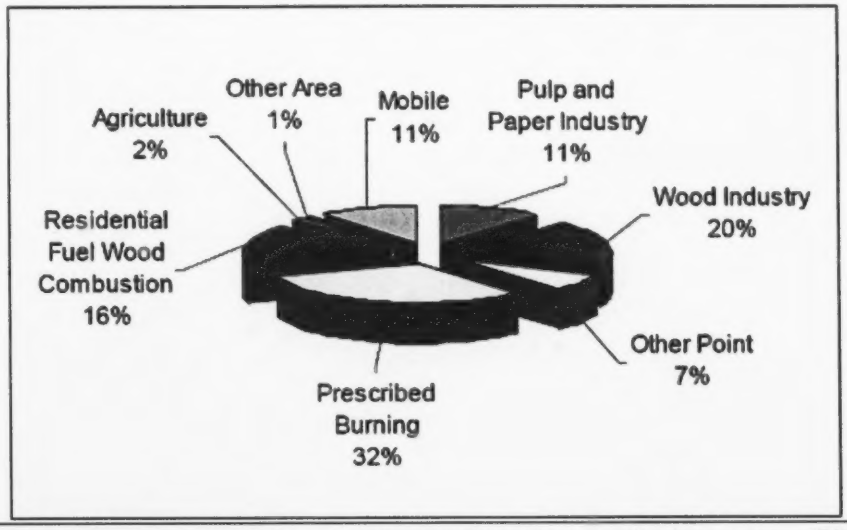

Figure 6: Human-caused sources of respirable (fine) particulate matter ($PM_{2.5}$)
The figure displays information for areas outside the Lower Mainland, and exclude natural sources, such as wildfires or **biogenic** emissions, and fugitive road dust.

Source: 2000 Emissions Inventory Analysis Report, MWLAP. 2004.

Of course, each airshed will have a unique mix of emissions and sources. While a rigorous emission inventory was not produced for the Radium airshed it is clear that the sources will be somewhat different than those indicated by the graphics in Figures 5 and 6. The main difference relates to the industrial base in Radium, where one saw mill (Slocan Forest Products) is the only major single point emission source and there are no pulp and paper operations. Other primary emission sources in Radium are residential heating, mobile sources (including resultant road dust), prescribed (including 'slash') burning, exposed lake/river beds, and wild fires.

The provincial government has implemented a number of programs to reduce the amount of particulate matter emitted into the atmosphere. Regulations have been passed to reduce smoke from land-clearing fires[23] and wood stoves[24]. Model bylaws have been developed to assist local governments in restricting backyard burning[25] and managing wood burning appliances[26]. Beehive burners are being phased out, beginning in the most smoke-sensitive areas of the province.

Common sources of fine particulate matter ($PM_{2.5}$) are: smoke from burning of wood waste or garden refuse, slash burning, residential woodstoves, exhaust from car and truck engines, as well as industrial smoke stacks. In addition to sources that come from human activities, $PM_{2.5}$ is also produced by natural processes such as wildfires.

[23] http://www.qp.gov.bc.ca/statreg/reg/E/EnvMgmt/145_93.htm
[24] http://www.qp.gov.bc.ca/statreg/stat/E/03053_06.htm#section75
[25] http://www.env.gov.bc.ca/air/particulates/pdfs/bylaw.pdf,
[26] http://www.ec.gc.ca/cleanair-airpur/975A1778-B583-4E2A-9369-81800C3AC8C2/Model_By-Law.pdf

Depending on meteorological conditions, it is possible for particles to stay suspended in the air for long periods of time, resulting in poor air quality. For particles in the $PM_{2.5}$ size fraction, this can allow particles to travel over hundreds of kilometres over time spans of days to weeks.

The larger particles which make up the rest of the coarser particulate matter (PM_{10}) usually consist of finely ground up rock and clay. Course particulate matter may originate from both human (i.e., industrial) and natural (i.e., forest fire) sources.

4.2 Influences on Air Quality: Weather and Terrain

Besides emission sources, both human-caused and naturally occurring, there are other factors that play an important role in ambient air conditions. Of primary importance are the influences of complex terrain (i.e., deep valleys) and weather conditions. Winds in the airshed generally are aligned with the valley orientation (north-northeast to south-southwest), which may be the result of either valley channelling or diurnal valley flows (Figure 7). In either case, the town of Radium is more susceptible to particulate matter emissions from these directions.

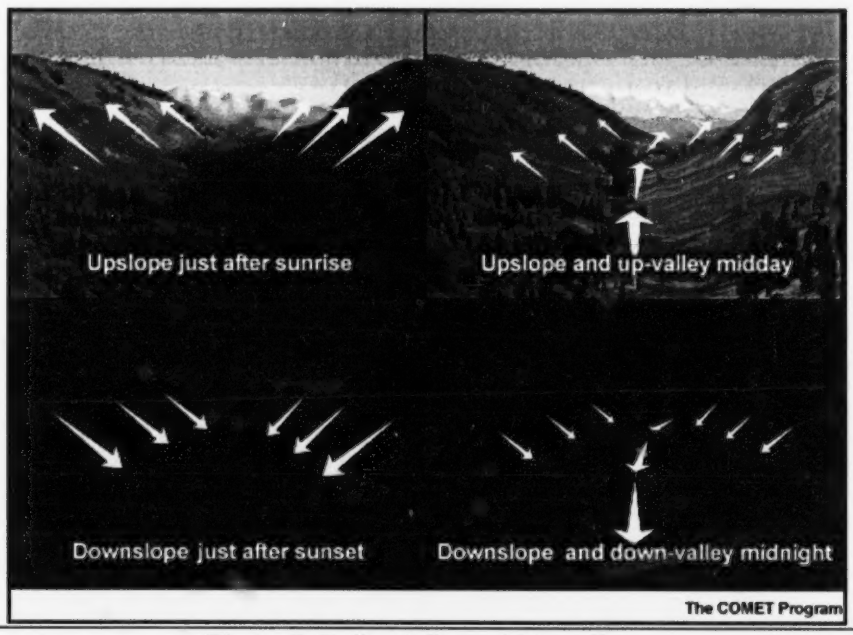

Figure 7: Daily airflow within valleys.
Airflow During the Daytime Tends to be Upslope and Up-valley. During the night time this tendency reverses and denser, cooler air pools in valley bottoms.

Source: The Cooperative Program for Operational Meteorology, Education, and Training (COMET®) Web site at http://meted.ucar.edu/ of the University Corporation for Atmospheric Research (UCAR), funded by the National Weather Service. ©2002, UCAR. All Rights Reserved.

Wind speed and direction are important drivers of ambient air pollutant levels. Generally, low wind speeds, like those often encountered during stagnant winter time conditions, impede the ability of the atmosphere to disperse pollutants. Of course, wind direction dictates whether pollutants from any one source are being carried towards or away from an air quality sampler.

Natural topographic features often bound an airshed. In the case of the Radium airshed, the Purcell Mountain Range and the Rocky Mountain Trench play a large role in determining the containment and/or dispersion of air pollutants. The steep valley walls surrounding Radium make the airshed susceptible to a higher frequency of temperature inversions, which are common in communities located in mountain valleys or nestled up against a mountain range. Cold air sinks to the valley floor or base of the mountains and because it is denser than the warmer air, it remains trapped by the warm air above. These stagnant conditions prevent upward mixing of the air, allowing pollutant levels to increase near the surface, as shown in Figure 8. This is most prevalent during the night but can also occur during the day, especially during the winter season when daylight hours are reduced.

Steep valley walls make Radium more susceptible to temperature inversions.

In Radium, these prolonged periods of inversions can have serious health effects, especially for those with respiratory problems, as well as children and the elderly. Thus, air quality in Radium remains a concern for the Ministry because of pollutant concentrations during inversions.

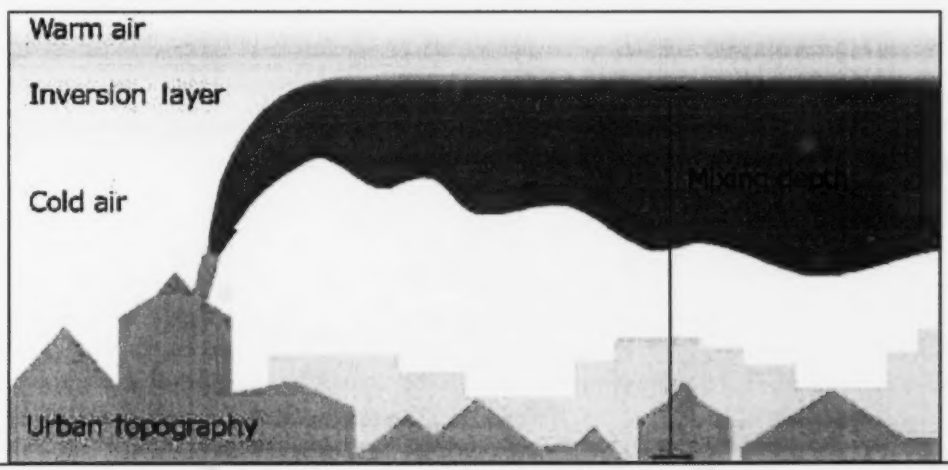

Figure 8: Diagram of a temperature inversion.
The warm layer of air on top of the cold layer creates an inversion layer that traps emissions close to the ground.

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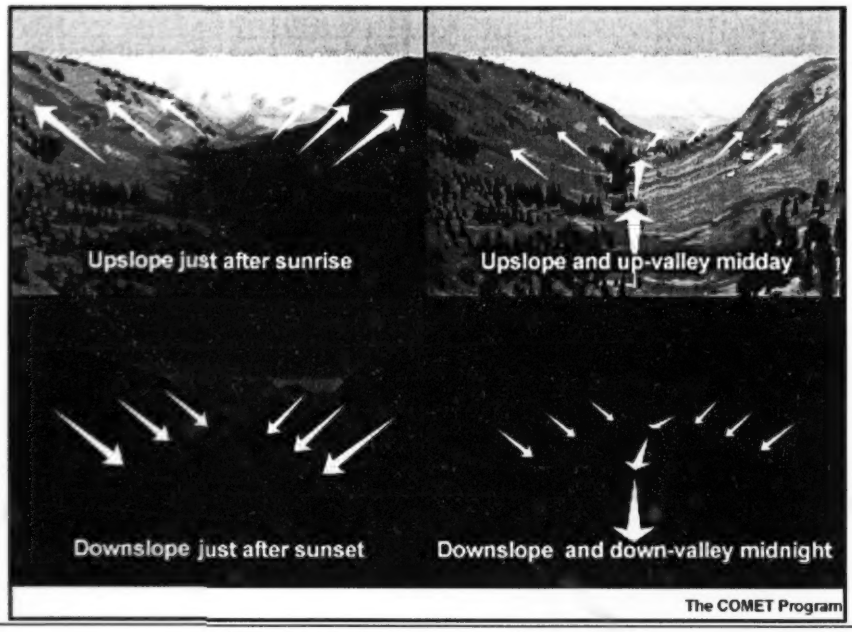

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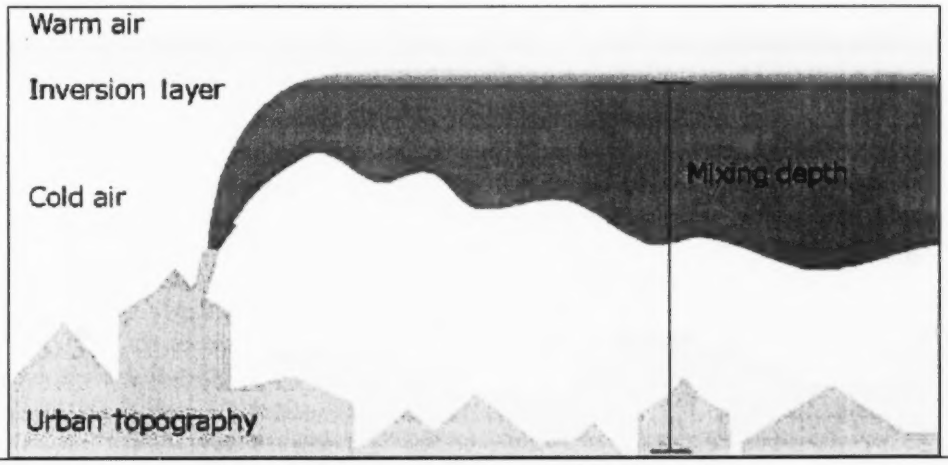

Figure 8: Diagram of a temperature inversion.
The warm layer of air on top of the cold layer creates an inversion layer that traps emissions close to the ground.

Source: Graphic courtesy of Environment Waikato, Government of New Zealand

The distance between the surface and the inversion layer is called the "mixing depth", and it has a major influence on the dispersion capability of the atmosphere (the analogous term "mixing height" is used for the height above sea level). The greater the mixing depth or height, the greater the volume of air in which pollution emitted at the ground can mix, resulting in lower concentrations. The height of this mixing layer is driven primarily by hours of sunlight and is therefore seasonal in nature. Figure 9 demonstrates that the long hours of sunlight in summer cause a much greater mixing height, and the winds are capable of dispersing pollution well. Conversely, in winter, the small amount of sunlight results in very low mixing heights, so pollution does not get dispersed and PM concentrations can rise.

A graph depicting mixing heights in Radium airshed is not available; therefore, mixing heights in the nearby airshed pertaining to Golden is displayed instead.

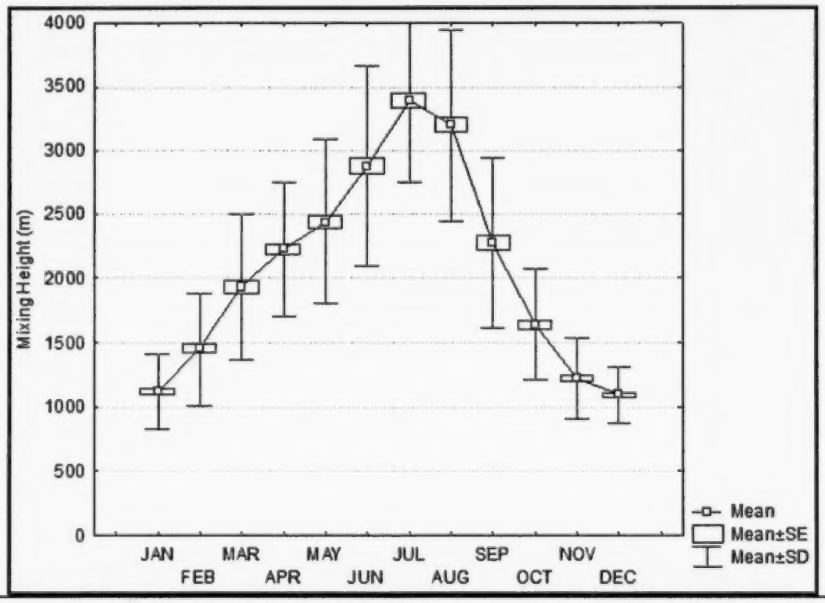

Figure 9: Annual cycle of mixing heights at Golden airport

The graph shows how much vertical movement of air (mixing height) occurs in Golden in each month of the year. Starting from a base elevation of 785 m (metres above sea level), the mean mixing height in winter (December and January) is about 1100 m, (or 315m above the surface) compared to almost 3500 m in July and August. The vertical bars represent the range of mixing heights for approximately 68% of mixing height readings.

Source: GEM-Scribe VI model output data from Jan 2002 to June 2007, courtesy of Environment Canada, Pacific Yukon Region. "SE" refers to a statistical term, "standard error". "SD" refers to a statistical term, "standard deviation".

5.0 Air Quality in Radium

As explained above, there was one manual sampler located at the Village of Radium office building which was used to assess the air quality. Since 1998, Slocan Forest Products has provided funding to operate this PM_{10} sampler in Radium. More recently, additional funding has come from the Village of Radium and the Ministry of Environment.

The monitoring history in Radium is considered to be relatively short, but it is still useful to look at some of the trends and bring awareness to the state of air quality in the airshed. Table 2, below, shows the results of the monitoring since the operation began.

Table 2: Summary of annual PM_{10} in Radium from 1998 to 2006

The mean and maximum values for each year are for 24 hour averages. These values are measured in micrograms per cubic metre ($\mu g/m^3$). The percent of days with Fair, Poor, and Very Poor air quality are measures of exceedances of NAAQO levels, showing the percentage of days where PM_{10} exceeded Level A (25 $\mu g/m^3$), Level B (50 $\mu g/m^3$), and Level C (100 $\mu g/m^3$), respectively. The Exposure Indicator is a cumulative factor of the time exposed to PM_{10} above a reference health level of 25 $\mu g/m^3$ (see Appendix E for the method of calculation). The CWS indicator adopts the algorithm for the Canada-Wide Standard for $PM_{2.5}$ which uses the three-year running average (98th percentile). The CWS indicator column refers to three-year running averages of 98th percentile PM_{10} values, and CWS Indicator values may be used to compare coarse PM levels between communities. Refer to Appendix B for a description of the calculation of exposure.

Year	Number of Samples	Mean ($\mu g/m^3$)	Maximum ($\mu g/m^3$)	Fair Days (%)	Poor Days (%)	Very Poor Days (%)	98th Percentile ($\mu g/m^3$)	NAAQO Exposure	CWS Indicator ($\mu g/m^3$)
1998	23	14.1	31	13	0	0	31	47.6	N/A
1999	55	11.3	55	2	0	0	24	6.6	N/A
2000	59	15.7	59	14	0	0	38	61.9	30.8
2001	46	15.3	46	13	0	0	33	55.5	31.4
2002	45	16.2	60	11	2	0	48	97.3	39.4
2003	47	17.8	57	23	2	0	48	147.6	42.8
2004	59	12.2	62	7	2	0	35	55.7	43.5
2005	53	16.0	74	8	4	0	63	103.3	48.7
2006	44	14.9	51	14	2	0	44	99.5	47.3

5.1 Results and Trends

The results of the Radium air quality monitoring program indicate the mean PM_{10} concentration has not changed dramatically from 1998 to 2006 (Table 2).

Radium's particulate matter levels are below those in other Kootenay communities.

The detected levels of particulate matter in Radium appear to be well below levels observed in most other British Columbian communities (Figure 10). Still, every year there are a number of days which exceed the NAAQOs health reference level and Level A of the provincial AQI. For example, in 2006, 16% of the recorded days were above the minimum long-term NAAQO health reference level (and AQI Level A). Health officials have observed more serious effects with increasing levels of PM. Children, the elderly, and those with respiratory problems are especially at risk.

Radium does appear to have relatively low atmospheric concentrations of particulate matter; however, some caution should be exercised when interpreting the PM data (Figure 10). An increase in health impact indicators is observed in the last two years of data (2005 and 2006) compared with 2004 suggesting a trend of increasing ambient PM concentrations may be occurring in Radium airshed. The annual mean PM value observed in 2005 is 31% higher than that of 2004, and the value in 2006 is 22% higher than the 2004 value.

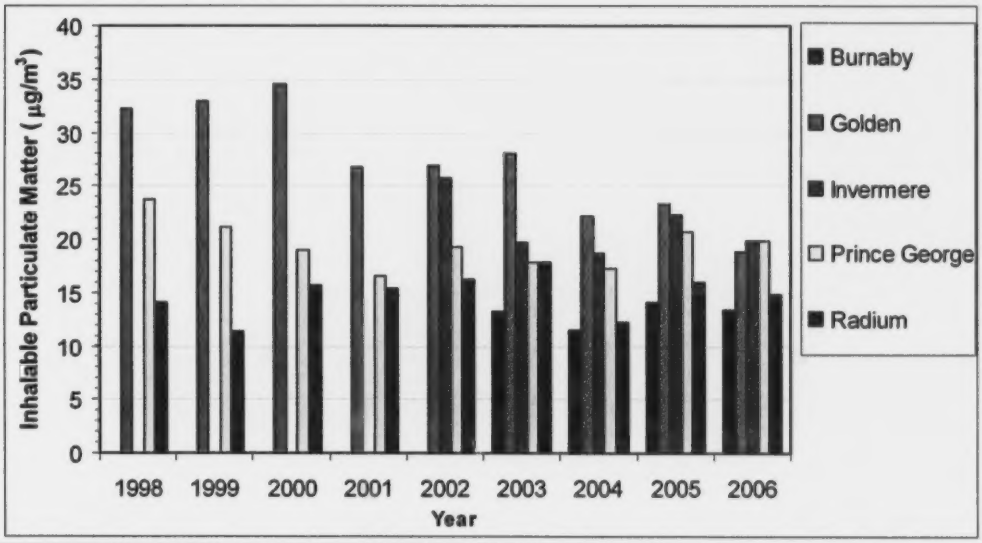

Figure 10: Comparison of mean annual PM_{10} concentrations with other communities in the Kootenay Region.

Even though the last two full years of monitoring (2005 and 2006) exhibited PM levels higher than that of 2004, the mean annual PM value of 2006 is merely the 6th highest of the 9 years examined in the Radium airshed monitoring program. The health indicator that supports perhaps more compelling evidence that PM levels increased[27] in the Radium airshed is NAAQOs exposure. NAAQOs exposure values depict the number of days an airshed experiences elevated levels of PM as well as the magnitude of the levels on those particular days. Aside from 2003, the highest NAAQOs exposure levels were observed in 2005 and 2006 suggesting that residents within the Radium airshed were experiencing days of elevated PM levels more frequently. In particular, data from 2006 produced a relatively low mean annual PM value but high NAAQOs exposure, indicating days with elevated levels of PM are not occurring as extremely high PM anomalies, rather they are occurring commonly at lower levels. The NAAQOs exposure (and mean annual PM value) of 2003 is the highest recorded during the 9 year monitoring period; however, exposure values of that year were heavily influenced by unusually severe forest fire activity. Consequently, disregarding the anomalous health indicator statistics derived from 2003 data, analysis of air quality data from 2005 and 2006 displayed an increase in exposure to PM by people in the Radium airshed.

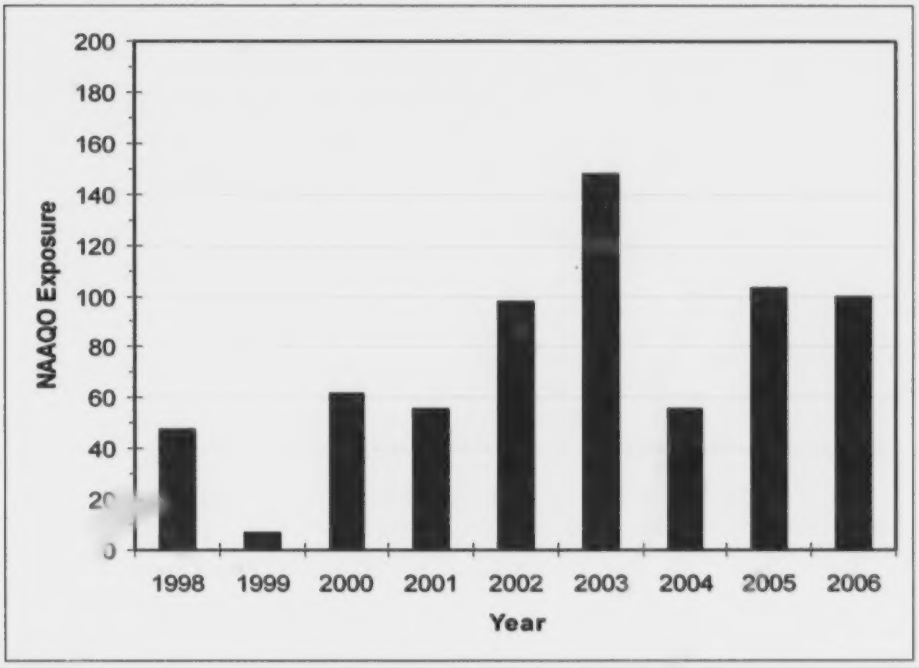

Figure 11: NAAQO exposure.
The NAAQOs also define an exposure to PM_{10} above a reference health level of 25 $\mu g/m^3$. Refer to Appendix B for a description on the calculation of exposure.

[27] The increase in PM levels is occurring over the short-term (i.e., from 2004 to 2005/2006); thus, a definitive long-term trend can not be exptrapolated from the observed PM increase. Consequently, future levels of PM in Radium can not be predicted with confidence using the data available.

Although an increase in NAAQO exposure between 2004 and 2005 was observed (Figure 11), Figure 12 illustrates that the exposure in the Radium airshed was relatively low compared to other Kootenay communities (such as Golden), which is an important fact. Figure 12 displays PM exposure experienced in Radium were dramatically lower than those of Golden, and Radium airshed could be considered to have good air quality (in comparison to nearby airsheds).

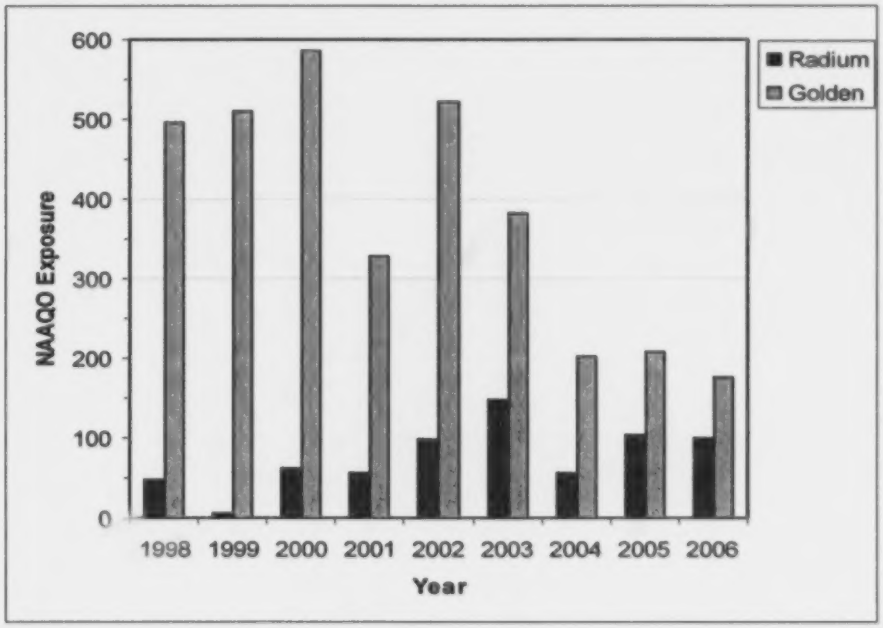

Figure 12: NAAQO Exposure comparison between Radium and Golden.

The PM trends in Radium displayed in Figure 10 to 12 demonstrate the influence of natural pressures such as inter-annual climate variability. Meteorological conditions may favour dispersion in certain years; therefore, the years that conditions favour dispersion may have lower particulate matter concentrations and vice versa. For example, high levels of ambient particulate matter were observed in the 2002/2003 winter season due to stagnant (low wind) atmospheric conditions dominated much of the December and November weather patterns. Poor dispersion of particulate matter resulting from the decreased wind activity is incorporating into the high particulate matter values of 2002 and 2003 observed in Table 2.

The data trends displayed in the report should interpreted with some caution because, instrument placement that will result in data that is indicative of the entire airshed, is a daunting task for Ministry staff and is rarely achievable with one instrument. The monitoring site in Radium may have had limitations, in that it may not have represented ambient conditions with potentially higher particulate levels at some of the more northern

locations in this airshed. In addition, data trends may be influenced by the fact that the air sampler may not have been fully operational throughout the entirety of some years.[28]

5.1.1 Particulate Matter Analysis

As previously stated, PM particulate matter is made up of many size fractions. Our instruments typically measure two of those size fractions: PM_{10} and $PM_{2.5}$. In order to conduct a detailed assessment of air quality in Radium, it is necessary to have measurements of both types of PM. Unfortunately, $PM_{2.5}$ data was not collected in Radium. Therefore, other less precise methods were used to extrapolate $PM_{2.5}$ levels and interpret particulate matter statistics.

Percentages of days in a month that experienced very poor, poor, and fair air quality are displayed in Figure 13. The graph shows six peaks in the number of days exceeding Level A and B objectives: one winter peak in November, two in February, three spring peaks in March and two summer peaks in August. Figure 13 is similar in shape to Figure 14, which displays the monthly averages of PM_{10} concentrations. With the exception of January and May, days with concentrations exceeding the NAAQO health reference level were observed in all months.

The March peak corresponds with the spring thaw which usually indicates that the increased particulate matter consists of fugitive dust. In Radium, the fugitive dust primarily originates from road dust. Road traction material, frozen during the winter, as well as naturally occurring dust, begins to thaw and is picked up by winds and traffic. This contributes to higher concentrations of particulate matter. Particulate matter during this time of year consists more of the coarse fraction than of the fine fraction ($PM_{2.5}$).

The August peak may be a result of fugitive road dust from dry summers or from forest fires around the region. Forest fires result in higher levels of both the coarse and the fine fractions of PM; the latter having more severe health impacts than PM_{10}.

During November, slash burning activities are increased. This combustion source would result in higher levels of $PM_{2.5}$ and PM_{10}. Another contributor in November could be the use of woodstoves for residential heating, or the saw-mill. The saw mill may have a greater impact in the winter as there is less dispersion in these months. The November peak is of concern to health officials as the sources contributing to this peak typically contain large amounts of $PM_{2.5}$

[28] Note, however, that the missing months were January, February, and March; these months typically show above average levels of PM10. Hence, the yearly average reported for 2002 may actually be underestimated. Refer to Figure 13-14: Exceedances By Month.

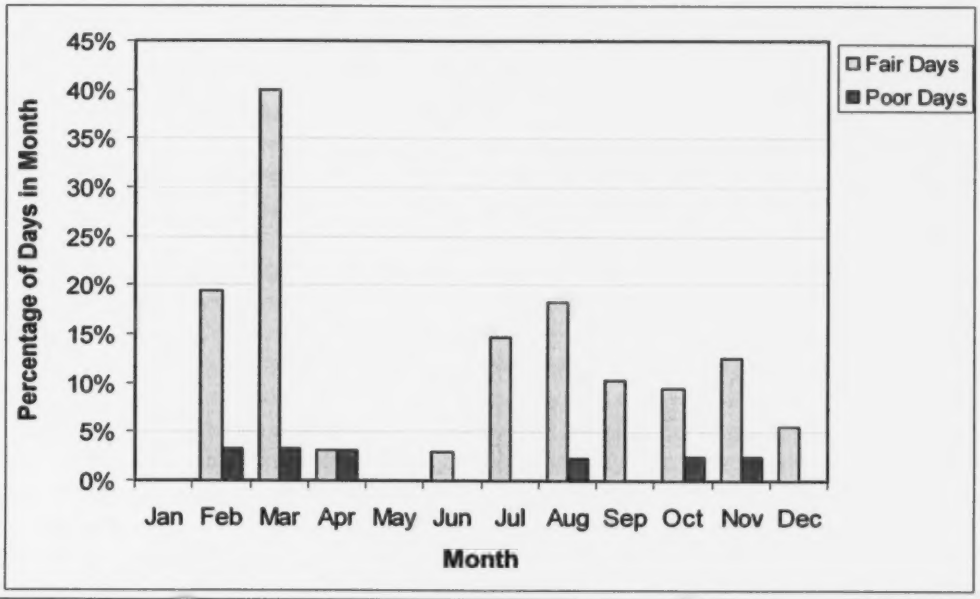

Figure 13: Percentage of days exceeding level A NAAQOs by month.
The percentage days in a month (during the period 1998 to 2006) when Radium PM exceeds Level A and Level B of the provincial AQI. The percentage of very poor, poor, and fair days measured in each month are shown by the bars. Sample Size =420 days.

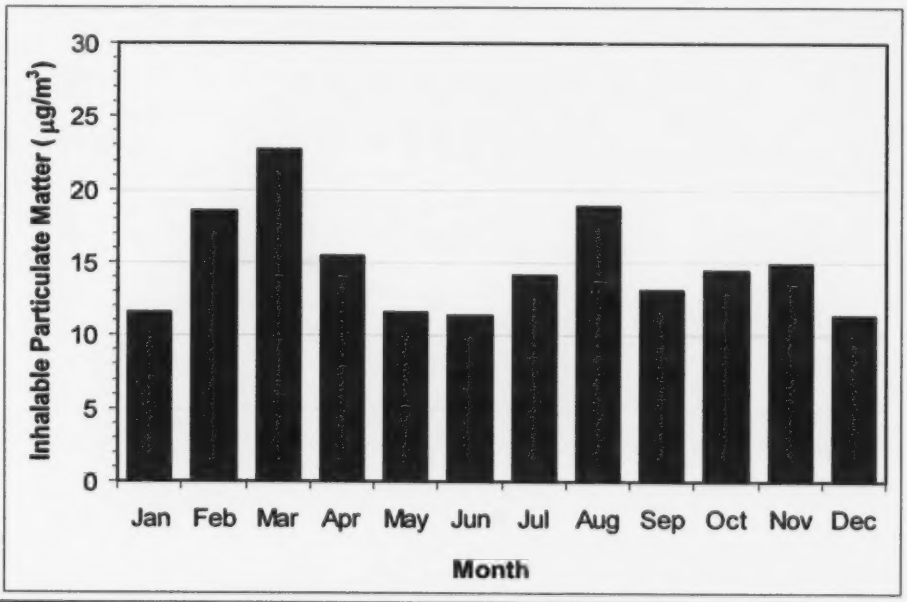

Figure 14: Monthly PM_{10} concentrations.
Radium's daily mean PM_{10} during the period 1998 to 2006 measured in each month are shown by the bars.

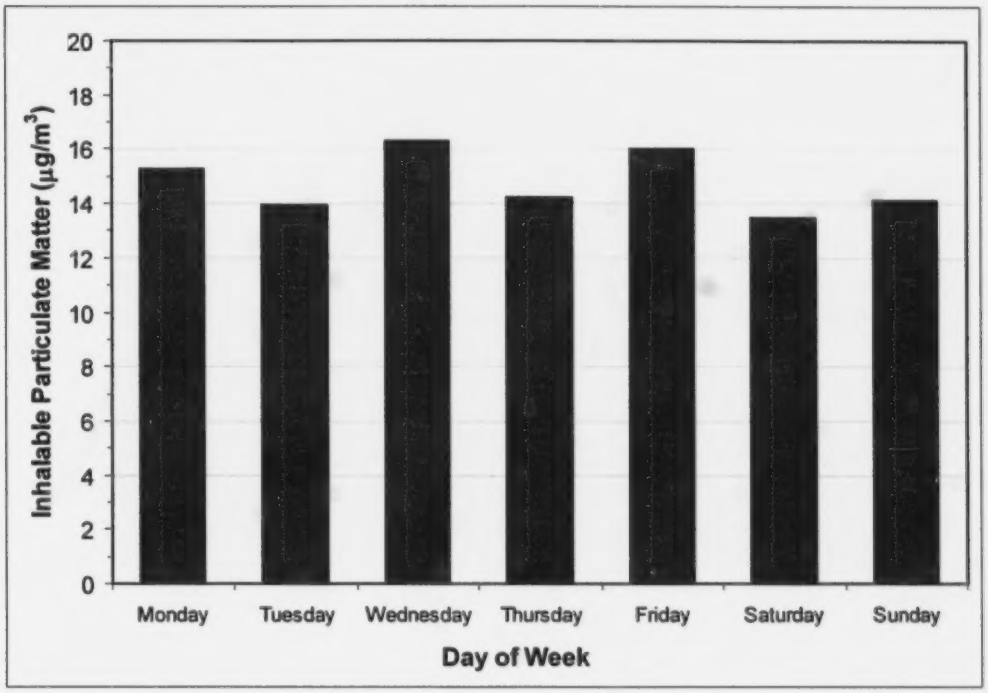

Figure 15: PM_{10} concentration by day of week.
PM_{10} for the period 1998 to 2006 measured on each weekday is shown by he bars.

During other times of the year, fugitive dust sources, industrial emissions, woodstove smoke, slash burning activities, and forest fires all contribute to exceedances of the objectives for acceptable air quality. Emissions from combustion sources result in higher levels of $PM_{2.5}$.

PM_{10} concentrations do not show much variation throughout the days of the week (Figure 15). Slightly higher values during the Monday to Friday work week are usually attributed to fugitive dust and vehicle emissions from increased commuter traffic. In many other areas, there is a more significant drop in particulate matter on the weekend. The absence of this decline in Radium may be due to the nature of traffic in Radium. Radium's traffic is generally from the highway, which has a high weekend tourist contribution. Thus we would not expect to see the day-of-week variations due to the Monday to Friday work week.

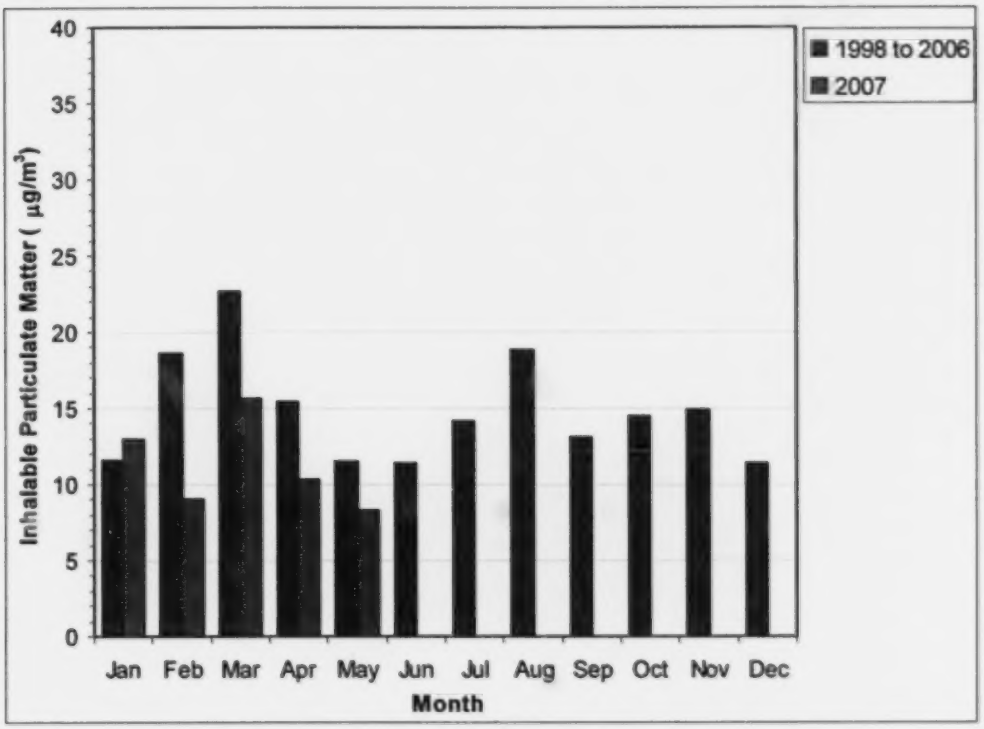

Figure 16: 2007 PM data compared with previous years.
The bars representing the 1998 to 2006 series are derived from average PM values calculated for all data collected between 1998 and 2006. The 2007 series depicts values derived from data for the first six months of 2007 only because the remainder of the year's data is currently unavailable.

Figure 16 displays a comparison of PM_{10} mean monthly values for 2007 with mean values of all the previous years PM monitoring was conducted in Radium (i.e., 1998 to 2006). Data was collected for only the first five months of 2007 before the sampler was relocated; however, available data depicts 2007 for the most part, as a year with distinctively low levels of PM_{10}. Aside from January when the 2007 mean PM_{10} value exceeded the mean of total previous years, PM_{10} levels during the first half of 2007 appear to be low relative to all other years monitored in Radium. More specifically, the drop in monthly mean PM_{10} values in 2007 (during February to May) were between 35% and 75% of the means for previous years. However, we cannot conclusively state that Figure 16 indicates PM_{10} concentrations are decreasing in Radium. Again the period of record is not sufficient to state whether the increase in health indicators in 2005 and 2006 relative to the late 1990s, or the decrease in PM concentrations in 2007 are indicative of any trend.

6.0 Conclusions / Recommendations

In summary, this is what we know about the air quality in Radium:

- Although the air quality monitoring period in Radium airshed has been relatively short making air quality trends difficult to ascertain, every year monitored in Radium appears to have experienced good air quality relative to provincial air quality objectives. Therefore, MoE does not have a major concern regarding air quality in the Radium airshed. Consequently, the air quality monitoring station was removed from the Radium airshed midway through 2007 to be deployed in an airshed with degraded air quality. Ultimately, focusing air quality monitoring efforts in areas of concern, increases MoE's ability to appropriately allocate air management strategies in a manner that improves our province's air quality as a whole.

- Every year, particulate matter concentrations exceed the NAAQO health reference level of 25 $\mu g/m^3$ for several days. However, in comparison to other BC communities, air quality in the Radium airshed is quite good. The average annual PM values in Radium over the last decade (since 1998) have been well below the NAAQO health reference level of 25 $\mu g/m^3$ and Level A of the provincial AQI (also 25 $\mu g/m^3$).

- The last full year of analyzed data indicate an upward trend compared to all health impact indicator thresholds. However, data from the truncated monitoring year of 2007 provides some evidence that perhaps the recent upward trend may reflect the year to year variability in weather and dispersion one might expect, rather than a statistically valid upward trend. Only additional sampling in future years can answer questions regarding the current trends in ambient PM levels.

- Exceedances of the NAAQO health reference level are concentrated in specific winter, spring, and summer months. These peaks have been linked to possible natural and human causes. Continued monitoring for a period, on a routine frequency, will aid in identifying what causes these peaks.

- Sources of pollutants during high months of particulate matter are difficult to identify because only PM_{10} data is available for Radium. However, the current report suggests the high levels observed during the November peak consist mostly of $PM_{2.5}$ because of the types of emission activity associated with the month. $PM_{2.5}$ emissions are more of health concern than PM_{10} emissions.

- Although particulate matter levels in Radium were lower than in many other communities, PM_{10}, even relatively low PM levels may have an impact on community health.

The following recommendations have the potential to improve the current air quality in Radium:

- An upward trend in PM may be occurring within Radium airshed; therefore, the ministry will consider reinstituting air monitoring in Radium in future to check if air quality levels of PM have changed significantly.

- Local residents and municipal governments are encouraged to engage in air quality management planning. A tool to assess the need for planning and the options to consider has been developed, and can be accessed at the following websites:
  - http://www.airqualityplanning.ca
  - http://www.env.gov.bc.ca/air/airquality/pdfs/airshedplan_provframework.pdf

- Local government may consider collaborating with similar communities to explore other options for air quality management (such as implementing local bylaws or woodstove exchange programs) and consult with senior levels of government to utilise their expertise and assistance.

- Residents should be encouraged to buy more efficient wood-burning appliances (woodstoves) and local retailers should promote the benefits of improved appliances. Funding to subsidize the change-out of older, inefficient appliances should be sought (e.g., woodstove exchange programs).

- Residents should be educated in techniques of efficient woodstove operation, selection of fuel, proper wood storage, and proper curing practices of wood. For more information on wood/woodstove techniques that reduce air pollutants, explore Environment Canada's wood heating webpage:
  - http://www.ec.gc.ca/cleanair-airpur/Wood_Heating-WSC1A217A6-1_En.htm

- Local municipalities should continue to identify different/additional techniques that could result in more efficient winter road maintenance and reduction of road dust. Examples of such measures are more frequent street cleaning, coarser sand for roadways, and possibly the use of magnesium chloride to keep roadways clear of ice. A recent collaboration between the Ministry of Environment and the Ministry of Transportation and Highways has resulted in the development of a 'Best Management Practises' document which can be found at the following webpage:
  - http://www.env.gov.bc.ca/air/airquality/pdfs/roaddustbmp_june05.pdf

- Bylaw enactment and enforcement is another tool often used to improve local air quality. The following sites offer examples to help guide local levels of government in bylaw development:

- Backyard burning bylaw template:
  http://www.env.gov.bc.ca/air/particulates/pdfs/bylaw.pdf

- Wood stove bylaw template:
  http://www.ec.gc.ca/cleanair-airpur/default.asp?lang=En&n=975A1778-1

- Local and senior levels of government should always be cognizant of the poor dispersion capability in the winter season. The authorization process of agencies who are responsible for planned burning activities of industry or residents, should always inquire if alternatives to burning exist. If no alternative is feasible then a request should be made that burning be conducted in the spring time if possible and only during good venting periods.

For More Information

The Environmental Quality Branch of the Ministry of Environment has several reports on air quality at http://www.env.gov.bc.ca/air/airquality/index.html

A report on Air Quality in the Kootenays 1993-1999 is available at http://wlapwww.gov.bc.ca/kor/epd/pdf/kootenay_air_quality_report.pdf

The Environmental Protection Division of the Ministry of Environment in the Kootenay Region has information at http://wlapwww.gov.bc.ca/kor/

B.C. provincial legislation related to air quality is described at http://www.env.gov.bc.ca/air/airregs.html

The 2003 Provincial Health Officer annual report about air quality in British Columbia can be found at http://www.healthservices.gov.bc.ca/pho/pdf/phoannual2003.pdf

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Public feedback is welcomed

Appendices

Appendix A - Glossary and Abbreviations

98th percentile	In a sequential list of data values, the 98th percentile is the data value that is 98 percent of the way through the list from the smallest reading (or 2 percent below the highest reading). The absolute maximum reading is not used for analysis because an unusually high reading may be the result of outlier (or suspect) data and can distort the analysis unduly.
Aerosol	A particle of solid or liquid matter that can remain suspended in the air because of its small size (generally under one micron).
Air pollution	Degradation of air quality resulting from unwanted chemicals or other materials occurring in the air.
Airshed	A geographic area that, because of topography, meteorology, and/or climate, is frequently affected by the same air mass. In general, it is that body of air in which management strategies of any individual emission source can have a discernible effect.
Air Quality Index (AQI)	Reports levels of ozone, particulate matter, and other common air pollutants. Higher AQI ratings for a pollutant indicate higher levels of contaminants in an airshed. For guidance on how to compute the AQI, see http://wlapwww.gov.bc.ca:8000/pls/aqiis/air.info.
Anthropogenic	Produced by human activities.
ARB	Air Resources Branch, Ministry of Environment
Area source	An emission source of pollutants that covers a large, and sometimes poorly defined, area – sometimes call non-point source (e.g., prescribed burning and residential fuel wood combustion). Note: A single residential wood burning appliance is considered a small source of emissions, but many appliances together can emit a significant amount of emissions, and are collectively thought of as an area source, instead of many small point sources.
Biogenic	Having to do with living organisms as sources. For example, major sources of biogenic emissions in the Kootenay Region are trees.

Carbon monoxide (CO)	A colourless, odourless, poisonous gas, produced by incomplete burning of carbon-based fuels.
Central tendency	In statistics, a measure of the middle or center of a set of data. The arithmetic mean is the most commonly used, but median, mode, and geometric mean are also used.
CEPA/FPAC	The Canadian Environmental Protection Act Federal-Provincial Advisory Committee directs the development and assessment of National Ambient Air Quality Objectives (NAAQOs) for airborne pollutants.
Coarse fraction	Particulate matter with diameter between 2.5 and 10 microns ($PM_{10-2.5}$). Also referred to as "inhalable particulate matter."
CWS Indicator	A measure of the severity of maximum levels of $PM_{2.5}$ concentration. The 98th percentile of the daily means is determined for each year, then averaged for the last three calendar years (which reduced the influence of a particularly bad year). This value can then be compared to a given standard and to other communities. Though the CWS standard for particulate matter is limited to $PM_{2.5}$ concentrations, this report adopts this algorithm for PM_{10} analysis and comparison purposes.
Emissions Inventory (EI)	A list of air pollutants emitted into a community's atmosphere in amounts (commonly tonnes) per day or year, by type of source.
Exposure Indicator	A measure of the accumulated exposure to PM_{10} over a specified time (typically one year), taking into account both the concentration of PM_{10} and the length of time of exposure. Larger exposures indicate an increased risk to human health.
Fine fraction	Particulate matter with diameter less than 2.5 microns; $PM_{2.5}$. Also referred to as "respirable particulate matter".
Fugitive dust	PM_{10} from finely ground rock and clay, origination from human sources such as sand and gravel traction material applied to roads in winter, or from natural sources such as exposed lake beds and river banks.
Haze	Atmospheric aerosol of sufficient concentration to be visible. The particles are so small that they cannot be seen individually but are still effective at attenuating light and reducing visual range.

Inversion	An increase in temperature with height, which is the reverse of the normal cooling with height in the atmosphere. Warm air at ground level tends to rise, but because warmer air is already above it, vertical air movement is minimized, trapping atmospheric pollutants in the lower troposphere, and resulting in higher concentrations of pollutants at ground levels than would usually be experienced.
Mean	In statistics, an "average" (arithmetic mean) calculated by dividing the total of all values of a set of data by the number of values. (In special circumstances, the geometric mean is used instead)
Median	In statistics, the value closest to the middle in a ordered list of data values.
MoE	B.C. Ministry of Environment. (formerly Ministry of Water, Land, and Air Protection - MWLAP).
MELP	B.C. Ministry of Environment, Lands and Parks. (predecessor to MWLAP).
$\mu g/m^3$	Micrograms per cubic metre (concentration)
μm	Micrometres (10^{-6} m) (diameter)
Mobile sources	Motor vehicles and other moving objects that release pollution; mobile sources include cars, trucks, buses, planes, trains, motorcycles, and gasoline-powered lawn mowers. Mobile sources are divided into two groups: road vehicles, which include cars, trucks, and buses, and non-road vehicles, which includes trains, planes, and lawn mowers.
MWLAP	B.C. Ministry of Water, Land and Air Protection (formerly Ministry of Environment, Lands and Parks and now the Ministry of Environment).
NAPS	National Air Pollution Surveillance Network. NAPS was established by Environment Canada to monitor and assess the air quality in Canadian urban regions.
NAAQO	National Ambient Air Quality Objectives. Health-based pollutant concentration objectives, developed by Environment Canada and used as objectives and standards in B.C.
NAAQS	National Ambient Air Quality Standards. Health-based pollutant concentration limits established by the United

	States Environmental Protection Agency that apply to outside air.
Nitrates (NO^{3-})	The gases and aerosols that have origins in the gas-to-aerosol conversion of nitrogen oxides, e.g., NO_2; of primary interest are nitric acid and ammonium nitrate.
Nitrogen oxides (NO_x)	Gases formed mainly from atmospheric nitrogen and oxygen when combustion takes place under conditions of high temperature and high pressure; considered a major air pollutant and precursor of ozone.
NO_x	NO + NO_2 + poorly defined fraction of other NO_x species (given conventional analyzers).
Ozone (O_3)	A major component of smog. Ozone is not emitted directly into the air but is formed by the reaction of volatile organic compounds (VOCs) and NO_x in the presence of heat and sunlight.
Particulate matter (PM)	A generic term referring to liquid or solid particles suspended in the air.
$PM_{2.5}$	Particulate matter less than 2.5 microns in diameter: the fine fraction of PM, also called respirable particulate matter. Tiny solid or liquid particles, generally soot and aerosols. The size of the particles (2.5 microns or smaller, about 0.0001 inches or less) allows them to easily enter the air sacs deep in the lungs where they may cause adverse health effects. $PM_{2.5}$ also causes visibility reduction.
PM_{10}	Particulate matter less than 10 microns in diameter, including both coarse and fine fractions, also called inhalable particulate matter. Tiny solid or liquid particles of soot, dust, smoke, fumes, and aerosols. The size of the particles (10 microns or smaller, about 0.0004 inches or less) allows them to easily enter the respiratory system where they may be deposited, resulting in adverse health effects. PM_{10} also causes visibility reduction and is a criteria air pollutant.
$PM_{10-2.5}/PM_{coarse}$	Particulate matter between 2.5 and 10 microns in diameter; the coarse fraction of PM. Particles that are typically generated by mechanical grinding or crushing (e.g. road dust) but can include soot, ash and pollen (biogenic) particles. These particles are less likely to enter the air sacs of the lungs but instead are trapped by the mucous membranes and other lung defenses. Coarse particles are not deemed as dangerous to human health as $PM_{2.5}$ but are, nevertheless, associated

	with inflammatory symptoms such as asthma and other respiratory ailments.
Point source	An emission source of pollutants that remains in a small identifiable area (e.g., an industrial plant)
Primary particle	The fraction of $PM_{2.5}$ or PM_{10} that is directly emitted from combustion and fugitive dust sources.
Primary pollutant	The emissions discharged from a source that either retain their form or are transformed into secondary pollutants.
Secondary particle	The fraction of PM_{10} and $PM_{2.5}$ that is formed in the atmosphere. Secondary particles are products of the chemical reactions between primary pollutant gases, such as nitrates, sulphur oxides, ammonia, and organic products.
SO_2 See Sulphur dioxide	
Sulphur dioxide (SO_2)	A pungent, colourless gas formed as a byproduct of the combustion of fossil fuels.
TEOM	Tapered element oscillating microbalance. An instrument for the continuous measurement of PM.
Ultrafine fraction	Particulate matter with diameter less than 0.1 microns.
WHO	World Health Organization. The World Health Organization has identified objectives for yearly PM means and recommends means (calculated by averaging daily PM values over a year) should remain below objective levels. The objective for PM_{10} is 20 $\mu g/m^3$, and the objective for $PM_{2.5}$ is 10 $\mu g/m^3$.

Appendix B - Calculation of Exposure

An exposure calculation is a technique to combine the AMOUNT of a pollutant to which we are exposed, and the TIME that we are exposed to the pollutant. At the two extremes, a low concentration of a pollutant could be in the air for several months, yielding an exposure, but the same exposure would result if there was a high concentration of the pollutant for a few days and clean air for the rest of the time. (One of the assumptions is that these two types of exposures will have similar effects on human health.)

Exposure calculations are based on the assumption that there is a concentration (25 $\mu g/m^3$) below which there is minimal risk to health, and above which there exists a statistically significant greater health response. This reference level can be exceeded either by a short period of exposure to high concentrations, or a longer period of exposure to lower concentrations.

Although there are many different ways to calculate exposure, the values cited in this report were calculated based on the NAAQO definition. This method assumes that PM_{10} has negligible health effects until the daily average exceeds a reference health level of 25 $\mu g/m^3$. For days in which this threshold is exceeded, the difference between the daily mean and the reference level is computed, divided by 10, and rounded up to the nearest whole number. After this is done for each day in a particular year, the numbers are summed to provide an overall measure of exposure. An objective level of NAAQO exposure has not been identified; however, exposure values may be used in both inter-annual and inter-site comparisons.

Because the monitoring in Radium is done on a non-continuous basis, many days, for many years, did not have a daily average for PM_{10}. Thus, exposure values were extrapolated from the days for which daily averages were available.

For example, suppose that for a given year, 58 daily averages were available and the NAAQO exposure calculation is applied to this 58 day dataset, with a resultant value of 85. An estimate for the year can then be achieved by assuming that the days sampled are representative of PM levels over the entire year and scaling the level of exposure accordingly. Thus, for our example, since the year had 365 days, we can multiply 85*(365/58) = 534.9 to get an estimate of the NAAQO exposure for this year.

Appendix C1 1998 Sampling Results

*Monitoring began in July 1998

Month	Day	µg/m³
	5	<null>
	11	<null>
	17	<null>
	23	<null>
JAN	29	<null>
	4	<null>
	10	<null>
	16	<null>
	22	<null>
FEB	28	<null>
	6	<null>
	12	<null>
	18	<null>
	24	<null>
MAR	30	<null>
	5	<null>
	11	<null>
	17	<null>
	23	<null>
APR	29	<null>
	5	<null>
	11	<null>
	17	<null>
	23	<null>
MAY	29	<null>
	4	<null>
	10	<null>
	16	<null>
	22	<null>
JUN	28	<null>
	4	<null>
	10	<null>
	16	<null>
	22	15
JUL	28	8
	3	7
	9	**30**
	15	20
	21	17
AUG	27	10
	2	**31**
	8	12
	14	<null>
	20	<null>
SEP	26	<null>
	2	<null>
	8	<null>
	14	4
	20	10
OCT	26	21
	1	10
	7	**31**
	13	20
	19	19
NOV	25	10
	1	4
	7	10
	13	15
	19	11
	25	4
DEC	31	5

** **Bolded type indicates days exceeding NAAQ objectives**

Appendix C2 1999 Sampling Results

Month	Day	µg/m³
	6	<null>
	12	<null>
	18	10
	24	4
JAN	30	6
	5	4
	11	13
	17	13
FEB	23	8
	1	15
	7	14
	13	20
	19	<null>
	25	<null>
MAR	31	0
	6	17
	12	7
	18	15
	24	9
APR	30	8
	6	6
	12	8
	18	0
	24	12
MAY	30	16
	5	17
	11	10
	17	14
	23	15
JUN	29	5
	5	9
	11	11
	17	0
	23	13
JUL	29	21
	4	21
	10	12
	16	8
	22	12
AUG	28	21
	3	10
	9	7
	15	12
	21	24
SEP	27	6
	3	7
	9	12
	15	12
	21	**30**
OCT	27	20
	2	<null>
	8	20
	14	0
	20	17
NOV	26	12
	2	10
	8	11
	14	9
	20	0
DEC	26	9

** **Bolded type indicates days exceeding NAAQ objectives**

Appendix C3 2000 Sampling Results

Month	Day	µg/m^3
	1	10
	7	12
	13	11
	19	14
	25	19
JAN	31	<null>
	6	9
	12	6
	18	12
FEB	24	11
	1	14
	7	**45**
	13	**39**
	19	**31**
	25	**29**
MAR	31	20
	6	14
	12	14
	18	9
	24	12
APR	30	7
	6	10
	12	7
	18	21
	24	21
MAY	30	10
	5	14
	11	6
	17	11
	23	8
JUN	29	17
	5	6
	11	18
	17	**26**
	23	17
JUL	29	21
	4	16.7
	1	22.8
	16	6
	22	13
AUG	28	14
	3	12
	9	6
	15	24
	21	22
SEP	27	21
	3	12
	9	18
	15	**28**
	21	13
OCT	27	22
	2	15
	8	6
	14	6
	20	6
NOV	**26**	**26**
	2	**27**
	8	9
	14	11
	20	19
DEC	26	<null>

**** Bolded type indicates days exceeding NAAQ objectives**

ENVIRONMENTAL QUALITY

Appendix C4 2001 Sampling Results

Month	Day	µg/m³
JAN	1	6
	7	<null>
	13	8
	19	19
	25	8
	31	12
FEB	6	17
	12	9
	18	24
	24	13
MAR	2	23
	8	<null>
	14	**31**
	20	12
	26	8
APR	1	17
	7	11
	13	17
	19	9
	25	**40**
MAY	1	6
	7	15
	13	<null>
	19	14
	25	22
	31	10
JUN	6	8
	12	12
	18	6
	24	15
	30	6
JUL	**6**	**32**
	12	<null>
	18	<null>
	24	6
	3	11
AUG	**5**	**25**
	11	24
	17	<null>
	23	**28**
	29	20
SEP	4	16
	10	9
	16	**27**
	22	6
	28	7
OCT	4	11
	10	<null>
	16	9
	22	6
	28	18
NOV	3	<null>
	9	**30**
	15	<null>
	21	<null>
	27	<null>
DEC	3	<null>
	9	<null>
	15	<null>
	21	<null>
	27	<null>

** Bolded type indicates days exceeding NAAQ objectives

ENVIRONMENTAL QUALITY

Appendix C5 2002 Sampling Results

Month	Day	µg/m^3
JAN	2	<null>
	8	<null>
	14	<null>
	20	<null>
	26	<null>
FEB	1	<null>
	7	<null>
	13	<null>
	19	<null>
	25	<null>
MAR	3	<null>
	9	<null>
	15	<null>
	21	<null>
	27	<null>
APR	2	<null>
	8	21
	14	6
	20	19
	26	23
MAY	2	8
	8	13
	14	20
	20	20
	26	8
JUN	1	10
	7	10
	13	**34**
	19	6
	25	18
JUL	1	7
	7	9
	13	23
	19	16
	25	**31**
	31	4
AUG	6	23
	12	9
	18	5
	24	10
	30	**25**
SEP	5	9
	11	21
	17	4
	23	8
	29	8
OCT	5	13
	11	8
	17	11
	23	**46**
	29	20
NOV	**5**	**36**
	11	9
	17	12
	23	19
	29	**60**
DEC	4	15
	10	14
	16	4
	22	**30**
	28	4

** Bolded type indicates days exceeding NAAQ objectives

ENVIRONMENTAL QUALITY

Appendix C6 2003 Sampling Results

Month	Day	µg/m^3
	3	17
	9	13
	15	13
	21	13
JAN	27	10
	2	**27**
	8	**35**
	14	4
	20	15
FEB	**26**	**29**
	4	18
	10	<null>
	16	<null>
	22	<null>
MAR	28	<null>
	3	<null>
	9	0
	15	7.7
	21	24.2
APR	27	9.5
	3	10.9
	9	6.8
	15	13
	21	14
MAY	27	13
	2	<null>
	8	19.2
	14	6.9
	20	23.2
JUN	**26**	**44.2**
	2	14.7
	8	12.3
	14	10.1
	20	24.6
JUL	**26**	**28.3**
	1	
	7	17.5
	13	**32.5**
	19	**56.5**
	25	**37.2**
AUG	**31**	**30.5**
	6	**47.3**
	12	6.9
	18	10.4
	24	17.4
SEP	**30**	**33.1**
	6	**28.2**
	12	4.2
	18	13.3
	24	7.9
OCT	30	6.3
	5	**29.7**
	11	16.4
	17	3.8
	23	12.6
NOV	29	1
	5	16.6
	11	<null>
	17	12.4
	23	11.8
DEC	29	8.9

**** Bolded type indicates days exceeding NAAQ objectives**

ENVIRONMENTAL QUALITY

Appendix C7 2004 Sampling Results

Month	Day	µg/m^3
JAN	4	11.7
	10	19
	16	15.9
	22	15.2
	28	8.9
FEB	3	7.2
	9	<null>
	15	<null>
	21	15
	27	9.2
MAR	4	13.1
	10	30
	16	**26.5**
	22	**62.4**
	28	**35.1**
APR	3	<null>
	9	13.8
	15	12.2
	21	12.2
	27	11.5
MAY	3	10.4
	9	3
	15	8.2
	21	3.2
	27	5.7
JUN	2	9.2
	8	4.6
	14	1
	20	7.3
	26	11
JUL	2	6.6
	8	3.2
	14	6.4
	20	1
	26	19.5
AUG	1	17.7
	7	1
	13	33
	19	6.3
	25	3.4
	31	16.5
SEP	6	2.5
	12	18.1
	18	8.4
	24	3.8
	30	5.3
OCT	6	13.1
	12	5.5
	18	13.8
	24	12.8
	30	9.2
NOV	5	14.4
	11	2.8
	17	11.3
	23	7.8
	29	19.1
DEC	5	8
	11	5
	17	10.4
	23	22.9
	29	11.7

**** Bolded type indicates days exceeding NAAQ objectives**

ENVIRONMENTAL QUALITY

Appendix C8 2005 Sampling Results

Month	Day	µg/m^3
	4	21.3
	10	9
	16	7
	22	13.9
JAN	28	14.1
	3	17.3
	9	**43**
	15	**38**
	21	**64**
FEB	27	22
	5	**27**
	11	
	17	12
	23	12
MAR	29	7.3
	4	6.5
	10	11
	16	17
	22	**74**
APR	28	14
	4	15
	10	<null>
	16	<null>
	22	<null>
MAY	28	<null>
	3	11
	9	8.7
	15	18
	21	**25**
JUN	27	5.8
	3	<null>
	9	<null>
	15	<null>
	21	<null>
JUL	27	15
	2	15
	8	<null>
	14	14
	20	6
AUG	26	12
	1	8
	7	<null>
	13	10
	19	6
SEP	25	<null>
	1	8
	7	8
	13	5
	19	13
	25	17
OCT	31	14
	6	8
	12	9
	18	19
	24	8
NOV	30	11
	6	15
	12	17
	18	5
	24	4
DEC	30	8

**** Bolded type indicates days exceeding NAAQ objectives**

ENVIRONMENTAL QUALITY

Appendix C9 2006 Sampling Results

Month	Day	µg/m^3
	5	<null>
	11	7
	17	<null>
	23	<null>
JAN	29	8
	4	<null>
	10	**43**
	16	20
	22	20
FEB	28	1
	6	9
	12	**28**
	18	5
	24	**43**
MAR	30	25
	5	<null>
	11	<null>
	17	<null>
	23	8
APR	29	13
	5	16
	11	<null>
	17	<null>
	23	4
MAY	29	4
	4	3
	10	4
	16	8
	22	<null>
JUN	28	20
	4	<null>
	10	7
	16	10
	22	16
JUL	**28**	**28**
	3	18
	9	**31**
	15	22
	21	**38**
AUG	27	<null>
	2	4
	8	<null>
	14	5
	20	<null>
SEP	26	7
	2	**51**
	8	8
	14	<null>
	20	<null>
OCT	26	<null>
	1	<null>
	7	<null>
	13	<null>
	19	<null>
NOV	25	<null>
	1	<null>
	7	<null>
	13	<null>
	19	<null>
	25	<null>
DEC	31	<null>

**** Bolded type indicates days exceeding NAAQ objectives**

ENVIRONMENTAL QUALITY

Appendix C10 2007 Sampling Results

Month	Day	µg/m³
	5	12
	11	12
	18	13
	24	12
JAN	30	16
	5	8
	11	<null>
	17	10
	23	<null>
FEB	1	15
	8	8
	13	**28**
	19	21
	25	6.8
MAR	31	15
	6	19
	12	<null>
	18	<null>
	24	6
APR	30	6
	6	9.8
	12	<null>
	18	<null>
	24	6.8
MAY	30	<null>
	5	<null>
	11	<null>
	17	<null>
	23	<null>
JUN	29	<null>
	5	<null>
	11	<null>
	17	<null>
	23	<null>
JUL	29	<null>
	4	<null>
	10	<null>
	16	<null>
	22	<null>
AUG	28	<null>
	3	<null>
	9	<null>
	15	<null>
	21	<null>
SEP	27	<null>
	3	<null>
	9	<null>
	15	<null>
	21	<null>
OCT	27	<null>
	2	<null>
	8	<null>
	14	<null>
	20	<null>
NOV	26	<null>
	2	<null>
	8	<null>
	14	<null>
	20	<null>
DEC	26	<null>

**** Bolded type indicates days exceeding NAAQ objectives**

ENVIRONMENTAL QUALITY